Yuan, Mei and Yang, Jay (2008) The promotion of sustainability agenda for infrastructure development through knowledge management. In Naaranoja, Marja and Otter, Adden and Prins, Matthijs and Karvonen, Anu and Raasakka, Ville, Eds. *Proceedings Joint CIB 2008 Conference for Performance and Knowledge Management*, pages pp. 167-178, Helsinki, Finland.

The Promotion of Sustainability Agenda for Infrastructure Development through Knowledge Management

Mei Yuan, PhD Candidate
Jay Yang, Associate Professor
Queensland University of Technology, Australia (email: j.yang@qut.edu.au)

Abstract

Sustainability is being recognized as an integral part of business operation and industry development. However in the construction industry, the gap between advancement of research and real life applications in actual projects is still significant. For infrastructure projects, which can typically cause major disturbance to the natural environment, span over a long duration, require a multitude of professionals, and consume significant amount of resources, drawing close relevance to all facets of sustainability and ensuring maximum level of exposure on sustainable agenda and actions is imperative. To date, this has not been achieved to full potential due to a variety of reasons. One of the major obstacles is the inability among stakeholders to agree on, capture, disseminate and apply the knowledge required to improve sustainability during infrastructure development. Therefore, there is a need for an integrated framework to incorporate sustainability issues within the infrastructure construction process.

Knowledge management (KM) has been proven as a valuable tool for construction innovation. This paper introduces a research project aimed at establishing a knowledge framework for sustainable infrastructure development and using KM principles to raise. It discusses the identification and capture of decision making processes most appropriate to encapsulating the sustainability criteria for infrastructure, dealing with one-off project nature, multi-disciplinary teams, dynamic participation, and reliance on past experience and historical data. It also introduces the specific KM based approaches to promote the consistent application and measurement of sustainability criteria.

Keywords: sustainability, construction, infrastructure, knowledge management

1. Introduction

Through out history, civilization has depended on the ability and will of communities, cities and nations to finance, build, operate and maintain infrastructure, the physical backbone of societies. As the result of the strong growth of prosperity, population, and global competition, the demand of infrastructure is creating bottlenecks for economic development in many parts of the world and has become a global phenomenon [1, 2].

As the infrastructure systems always have significant impacts on environment, society and economy, the world demands for construction and regeneration of infrastructure can result in disturbances to human life and our ecosystems. Therefore, enhancement of sustainability in infrastructure development can be of crucial importance to not only increase economic benefits but also reduce adverse environmental, social, and cultural impacts. In this context, it is believed that sustainability should be put on top of the agenda when contemplating infrastructure development.

This paper introduces a research project aimed at promoting sustainability exposure and implementing its agenda and actions in developing infrastructure projects, through knowledge management. It begins with an overview of sustainability development in construction and how knowledge management may enhance opportunities of communicating the ideas between stakeholders of infrastructure projects, based on literature studies. It then discusses research objectives, methodologies and development processes of this on-going project undertaken at the Queensland University of Technology Australia., before highlighting potential deliverables.

2. Sustainability and construction

The importance of the sustainability agenda has been widely recognized in the 21st century. Since the milestone publication of the Bruntland Report, *Our Common Future*, in 1987, the concept of sustainable development was expanded to many aspects beyond economical, social, cultural and economical impacts. It is now widely recognized throughout the world and has been endorsed in many industries including the construction sector.

Sustainable construction can be seen as a way for the construction industry to respond to achieve objectives of sustainable development [3]. CIB (International Council for Research and Innovation in Building and Construction) provides the following description of sustainable construction: *"Sustainable construction means that the principles of sustainable development are applied to the comprehensive construction cycle from the extraction and beneficiation of raw materials, through the planning, design and construction of buildings and infrastructures, until their final deconstruction and management of the resultant waste. It is a holistic process aiming to restore and maintain harmony between the natural and built environment, while creating settlements that affirm human dignity and economic equity" [4].*

Figure 1 illustrates four potential landing points on sustainability for the construction industry, shown as a series of nested systems. The bigger the system is, the more complex the problem is, and the more actors are needed to be involved in its solution.

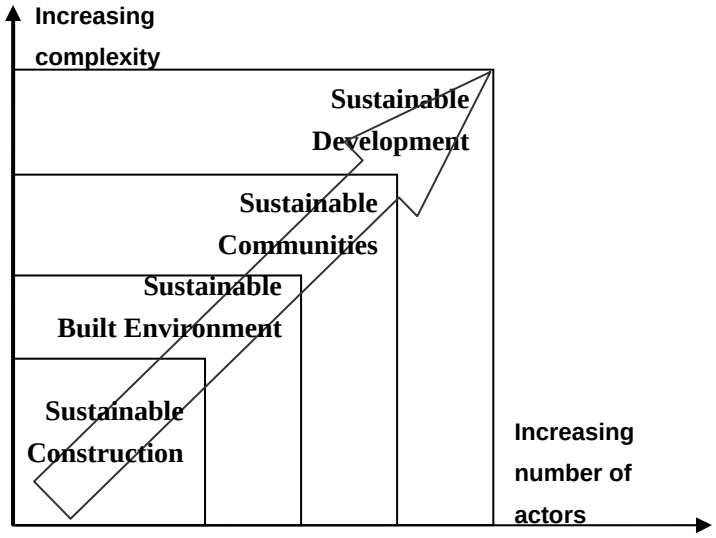

Figure 1: *Four potential landing points for the construction industry on sustainability issues* [5].

To date, the construction industry has taken on a positive response to support the agenda of sustainable development which can be indicated by the widely ranged sustainability initiatives by industry, academic researchers, and government agencies across the globe. Examples include:

- Report C563 Sustainable Construction: Company Indicators, produced by Construction Industry Research and Information Association (CIRIA) in 2001;
- Green File, produced by European Green Building Forum (EGBF) in 2001;
- Leadership in Energy and Environmental Design Green Building Rating System for New Construction and Major Renovations (LEED), produced by United States Green Building Council (USGBC) in 2002;
- GB Tool, produced by Cole R and Larsson N: International Initiative for a Sustainable Built Environment (iiSBE) in 2002;
- Environmental Assessment Method (BREEAM), produced by Building Research Establishment (BRE) in 2003;
- European Thematic Network PRESCO (Practical Recommendations for Sustainable Construction), produced by more than 20 organizations of 17 countries in 2005.

Helen and Peter [6] comparatively analysed the main documents addressing assessment and implementation of sustainable development in relation to the built environment and found that the actions called for most frequently across all documentations are focused on:

- the health and wellbeing of building users;
- enhancement and protection of the habitats, biodiversity and the natural environment;
- re-use and minimise use materials;
- minimise use energy and minimise use energy;
- minimise the risk of pollution and eliminate ozone depleting substances;

- minimise the creation of waste and recycle use ;
- minimise use and protect water;

However in this respect and despite the above governmental strategies and initiatives, sustainability considerations and applications in the construction sector are at the infant stage and much more has to be done to make all construction works more sustainable. It is widely acknowledged that sustainability is still a vague and evolving concept. Different definitions are held by different stakeholders and different aspects are emphasised in different countries due to their own priorities and special contexts [7]. And it is obvious that there is a gap between sustainability criteria and their applications at project level [8]. Myers [9] studied the construction companies' attitudes towards sustainability in United Kingdom and found that very few companies have positively and wholeheartedly embraced sustainable ideas and implemented them in their operations. Further more, specific sectors in construction, such as infrastructure, are often neglected by researchers therefore need immediate resurrection and adoption of the sustainability agenda.

3. Infrastructure in the context of sustainable development

In broad terms, construction projects can be divided into buildings and infrastructures. Urban infrastructure includes transportation, energy and utilities, and communications assets and networks. Distribution of essential public services to maintaining human living standard and continuing development, especially in highly congested urban environments, is heavily dependent on infrastructure systems. Infrastructures are often seen as backbone of a nation’s economy. Governments have long recognized the vital role that modern infrastructure services play in economic growth and poverty alleviation [10].

In fact, seen from the social respect and the wellbeing of human, especially in developing country, the development and improvement of infrastructure itself is often considered a natural step towards sustainable development. Katherine, Vice President for Sustainable Development of World Bank, said that “*By promoting economic growth strategies based on expanded infrastructure which are environmentally responsible and socially acceptable, we are bringing a sustainable future closer to today’s reality" [11]*.

The term “sustainable municipal infrastructure” is first used by the Federation of Canadian Municipalities, Infrastructure Canada, National Research Council of Canada and Canadian Public Works Association to describe the goal of their InfraGuide project operated from 2001 to 2007. To achieve sustainability in municipal infrastructure especially large scale urban infrastructure, they advocate environmental protocols and inclusion of ecological and social indicators and factors in decision making at the earliest possible stage [12]. InfraGuide's national network of experts produced a collection of case studies, best practice reports and e-learning tools for sustainable municipal infrastructure - offering Canadian infrastructure experience and knowledge. In their view, sustainability concerns apply to all of "maintaining, repairing and upgrading the infrastructure that sustains our quality of life" including at least:

- municipal decision making and investment planning
- potable water supply
- storm water and waste water especially minimizing the distance that such water travels to be treated and reused
- roads and sidewalks and their integration with transit systems to achieve smoother flow of people
- environmental protocols and multi-discipline practices to ensure they are respected, e.g. green procurement.

In academia, some researchers argued that for the purpose of promoting the sustainability, a major challenge for the engineer is the development of practical tools for measuring and enhancing the sustainability of urban infrastructure over its life cycle. Therefore, criteria, indicators, and frameworks are developed for the sustainability assessment issues in order to understanding and quantifying "how sustainable the infrastructure is, especially in design phases" [13-15].

Sohail et al consider that operation and maintenance (OM) has been identified by commentators as the key to enhancing the sustainability of existing infrastructure and assets. The community and government should work together to ensure the sustainability of infrastructure. The keys to improving operation and maintenance—and hence sustainability—are the availability of information and the attribution of clear roles and responsibilities [16].

Further more, the urban infrastructure system is really complex and performance of local infrastructure system is influenced by interactions with the greater urban region and other infrastructure. Thus careful considerations of these relationships could yield significant improvements in infrastructure sustainability [17, 18].

However through literature study, the authors have identified that up to now, compared to the research efforts on sustainable building development (e.g. Green Building, BREEAM, LEED, etc.), infrastructures attracted scarce attention. It is really a novel to promote sustainability agenda in infrastructure development, since no settled definition or operational guide, and thus has no settled body of existing practice or knowledge.

Due to the difference and complexity of infrastructure systems (e.g. inter-reaction between transportation and communication systems), the one-off nature of each infrastructure project, and the long time span of delivery, it is hard to deal with the comprehensive but hazy body of knowledge. Thus there is a call for an integrated approach which can provide a platform for all the stakeholders and the community to share ideas and experiences, to inspire new researches and practices, to enhance communication/education and assist decision-making of infrastructure, and thus to promote sustainability agenda in all the design, construction and development of new infrastructure, and the re-design, rehabilitation, re-use or optimization of existing infrastructures. Knowledge management (KM) may provide a suitable solution to the capture, storage and communication of information and knowledge involved in such an endeavour. KM principles and applications have proved their appropriateness in applications in the generic construction sectors over the last two decades.

4. Knowledge management

Knowledge management is a broad and expanding topic contributed by a diverse range of disciplines with a multifold mix of strategies, tools, and techniques [19-21]. There is a general agreement that in the simplest of terms, knowledge management is a body of knowledge that deals with the management of both personal and organizational knowledge [21].

Alavi summarized the existing taxonomies of knowledge, such as tacit knowledge vs. explicit knowledge, individual knowledge vs. social knowledge, declarative knowledge (know-about), procedural knowledge (know-how), causal knowledge (know-why), conditional knowledge (know-when), relational knowledge (know-with), etc. [19].

On the basis of some major approaches to KM cycles, Dalkir [21] distilled an integrated KM cycle and formulated a framework as outlined in Figure 2. Within the KM cycle, there are processes for data capture and creation of knowledge, the sharing and dissemination of results, and their application and update.

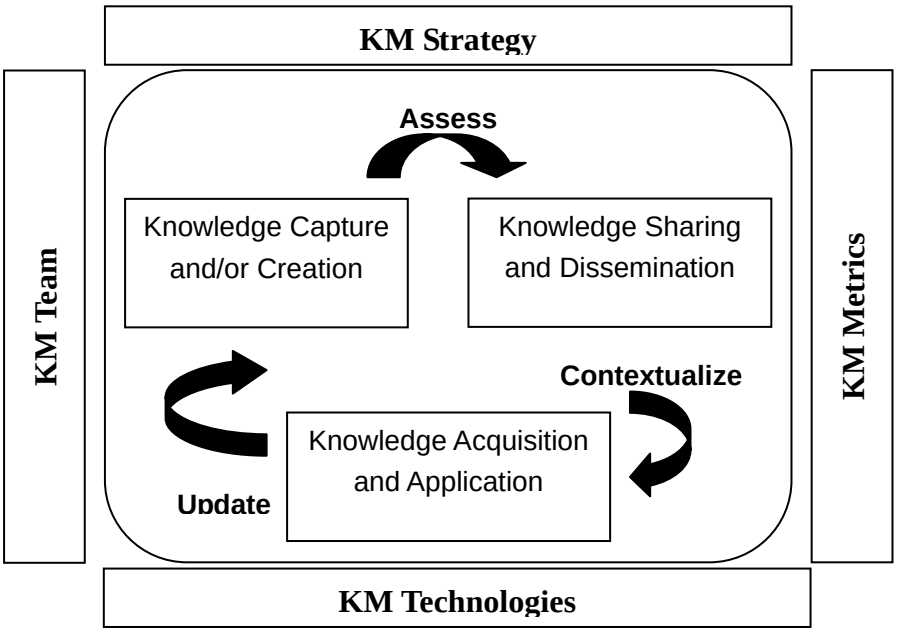

Figure 2: *The Integrated KM Cycle [21]*.

Knowledge plays a key role in today's fast-changing business environment and contributes largely towards sustained business performance in many commercial sectors. Knowledge management has also been imported into the construction industry as a modish concept as well as a useful tool for some years [22]. There are various concepts, methods, models, and tools supported by real-life case studies from various corners of the globe providing insights into the management of knowledge in the construction industry.

Explicit knowledge is knowledge that has been or can be articulated, codified, and stored in certain media (e.g. documents, guidelines) while tacit knowledge is knowledge that people carry

in their minds and is, therefore, difficult to access (e.g. experience, know-how) [21]. Many researchers argue that in construction industry, tacit knowledge which always embodied in experts minds, is a more important factor affecting an organization's ability to remain competitive [23]. Some researchers emphasized that organization should learn from experiences and pull knowledge from external resources which can deliver significant benefit to its projects [24].

A few early studies have attempted to apply the knowledge management concept in the area of sustainable construction. Venters introduced Softer System Methodology (SSM) as a method of conceptualising the industry's knowledge environment and thus moving towards technological interventions which aim to increase sustainability in construction industry practice [25]. Maqsood and Walker used SSM in case studies to identify innovation diffusion initiative within an organization. This research highlights the gap that exists between academic knowledge and its practical use by construction organizations [24].

Chen et al [26] presented an integrative knowledge management system for environmental-conscious construction based on a comprehensive integration of environmental management techniques and tools in construction. A project named C-SanD (Creating, Sustaining and Disseminating Knowledge for Sustainable Construction: Tools, Methods and Architecture) was conducted in UK universities recent years [25]. This research mainly focused on the creation of knowledge within construction industry in the context of sustainable development, developing knowledge management approaches to produce new sources of knowledge based on the exiting resources. The project developed a "Sustainability Management Activity Zone" (SMAZ) that maps onto a generic construction process – provided by the Process Protocol method. The portal was developed to aid stakeholders in the creation and management of their sustainability knowledge on construction projects and was tested to be a useful tool to aid knowledge implementation [27].

Knowledge management has been proven to be a valuable tool for sustainable construction innovation. However its application in infrastructure projects, particularly in connection with sustainability aspects, has been largely absent. Infrastructure construction presents a unique nature with many characteristics different to building construction works. These characteristics will need to be explored and factors influencing knowledge take-up and transfer identified. The next section introduces an ongoing research at the Queensland University of Technology designed to promote sustainable infrastructure development through knowledge management approaches.

5. The QUT Research

5.1 Research background, motivation and objectives

Due to the significant influence of infrastructure projects on urban economy, environment and society, sustainability should be put on the top of the infrastructure development agenda. Sustainability goals can only be achieved if constructions activities and development processes

are informed and guided by new resources of knowledge and expertise, with the reassurance of proper application of the knowledge at project levels.

With their own experiences and through literature findings, the authors attempt to categorise existing knowledge on sustainability for infrastructure development into four groups: assessment tools, government polices and guidelines, company procedures, and project experiences, as in Table 1.

	Assessment Tools (BREEAM, LEED, GREENSTAR, etc.)	**Government Guidelines/Polices** (InfraGuide, Agenda 21, PRESCO, etc.)	**Company Procedures**	**Project experiences**
Location	External resources	External resources	organizations	Individuals
Type	Explicit	Explicit	Explicit/tacit	Explicit/tacit
Character	• Mainly for building assessment and need further development.	• Vague and general.	• Hard to change; • Prevented to chare inter-organizations.	• mostly reside in people minds; • Hard to track, record and widely share.

Table 1: *Existing sustainable infrastructure knowledge*

However this should be viewed as a starting point as the body of knowledge is far from enough to encapsulate life experiences and expectations of all stakeholders. Further research has to bear the following issues in mind:

- Due to the evolving nature of the sustainable development and the different point of view hold by different stakeholders, what are the existing perceptions on sustainability held by various stakeholders in infrastructure projects?
- What is the level of sustainability knowledge application in infrastructure projects?
- How is the sustainability knowledge transferred between stakeholders? What are the barriers to facilitate effective transfer?
- How does the sustainability knowledge flow during the whole development processes? Are there processes that may lose such knowledge?
- What are the drivers and factors that influence the promotion and application of sustainability knowledge and hence to inspire the innovation and creation of new knowledge?

In search for answers to some of the above problems, a research project is being conducted through the use of specific knowledge management approaches to promote sustainability agenda and improve the level and efficiency of understandings with appropriate knowledge and information during infrastructure development.

The objectives of this research include:

- To identify the appropriate types and levels of sustainability knowledge application in infrastructure development;
- To identify the factors that will influence knowledge transfer; and
- To develop an integrated knowledge management framework for the promotion of sustainability knowledge application in infrastructure development.

5.2 Research methodology and develop processes

This research project is being developed using qualitative methodologies including questionnaire surveys and case studies. Reviews of academic research, industry standards, and governmental initiatives helped the researchers establish a broad spectrum of issues that could be applicable to knowledge management processes for sustainable infrastructure development. These issues are being tested, consolidated and confirmed by industry participants through two rounds of questionnaire based surveys. These surveys will determine how construction organizations capture and implement sustainability knowledge during various phases of infrastructure development. Results of this will help generate a preliminary KM framework which will then be verified through select cases studies. Final development will include formulation of contextual and visual representation of the final framework and the development of application guidelines, a procedure-driven "how to apply" operational manual. Figure 3 illustrates a research development process and information flow.

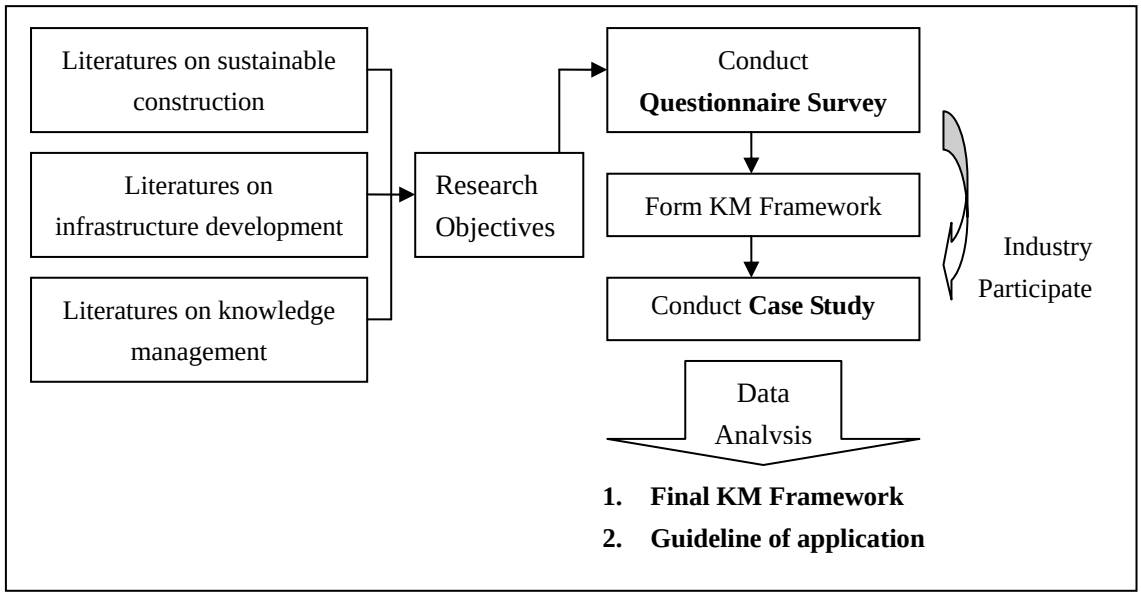

Figure 3: *A flow chart of research development processes*

In this research, industry participants will be involved in two phases, questionnaire survey and case studies. They will contribute to information supply and knowledge extraction from the direct vantage point of stakeholders, on what the processes/approaches/methods are for the various construction organizations they may represent, in order to implement the sustainability

principles. Respondents include Project Managers, Engineers, Designers, Developers, Contractors, as well as Government authorities who all play key roles to the lifecycle development processes and are involved in the decision making and knowledge flow and exchange. Several infrastructure projects that were carried out with sustainability foci by local companies in Australia will be selected as case studies for the purpose of verifying the initial KM framework. At the time of writing this paper, the researchers have completed the literature study in order to encapsulate potential issues. They have also formulated a process based knowledge application flow chart, which will be used as the basis to engage industry participants for their assessment and evaluation of the potential issues identified to date, through real life problem solving and decision points along project development. The on-going research is expected to be completed by mid 2010.

6. Conclusions

In recent years, economic development from around the world has been facing the bottleneck of inadequate infrastructures. The demand for new construction and the regeneration of infrastructures is likely to result in a flurry of projects and construction activities which may cause major implications on our natural environment with significant economic and social impact. Infrastructure projects typically span over a long period, require a multitude of professionals, and consume significant amount of resources. This makes it a top priority to draw relevance from all stakeholders and apply all facets of sustainability throughout the lifespan of this type of construction works. Despite the logic and expectation, to date, this has not been achieved to full potential due to a variety of reasons.

Knowledge management (KM) has proven itself as a valuable tool for construction innovation. It is particularly useful in dealing with complex issues and product/process development with a novice nature. To promote sustainability measures in infrastructure projects, which exhibit many unique characteristics, the knowledge management routines of data capture, creation of knowledge, the sharing and dissemination of results, and knowledge application and update, can be enhanced through frameworks understandable and acceptable to all stakeholders. An on-going research project in Australia is developing such a framework to demonstrate the appropriate levels of knowledge, identify issues that impact on knowledge take-up and transfer, and provide integration between key stages of decision making during the development of infrastructure projects. With keen participation of industry partners, this approach will ultimately promote the sustainability agenda among all involved in the large and complex projects of infrastructure.

References

[1] ERNST & Young. 2007. Investing in global infrastructure 2007: an emerging asset class. from http://www.ey.com/global/content.nsf/International/Real_Estate_Overview

[2] Asian Development Bank. 2007. Asian development outlook 2007 - Growth admit change, Asian Development Bank.

[3] Khalfan, M. M. A. 2006. Managing sustainability within construction projects (Publication: http://www.c-sand.org/Documents.htm)

[4] CIB & UNEP-IETC. 2002. Agenda 21 for Sustainable Construction in Developing Countries - A discussion document (WSSD Ed.). Pretoria: CSIR Building and Construction Technology.

[5] Construction Research & Innovation Strategy Panel. 1999. Sustainable Construction: Future R & D Requirements. London: CRISP.

[6] Bartlett, H. & Guthrie, P. 2005. Guides to sustainable built-environment development. Proceedings of the Institution of Civil Engineers - Engineering Sustainability 158(ES4): 185-195.

[7] Kibert, C. J. & Rinker, M. E. 2007. The next generation of sustainable construction. Building Research & Information 35(6): 595-601.

[8] Sahely, H. R., Kennedy, C. A. & Adams, B. J. 2005. Developing sustainability criteria for urban infrastructure systems. Canadian Journal of Civil Engineering 32(1): 72-85.

[9] Myers, D. 2005. A review of construction companies' attitudes to sustainability. Construction Management and Economics 23(8): 781-785.

[10] Brand, R. 2005. Urban infrastructures and sustainable social practices. Journal of Urban Technology 12(2): 1-25.

[11] Sierra, K. Sustainable development. from http://web.worldbank.org/

[12] Federation of Canadian Municipalities. 2007. InfraGuide: The National Guide to Sustainable Infrastructure. from http://www.sustainablecommunities.fcm.ca/Infraguide/

[13] Dasgupta, S. & Tam, E. K. L. 2005. Indicators and framework for assessing sustainable infrastructure. Canadian Journal of Civil Engineering 32: 30-44.

[14] Sahely, H. R., Kennedy, C. A. & Adams, B. J. 2005. Developing sustainability criteria for urban infrastructure systems1. Canadian Journal of Civil Engineering 32(1): 72-85.

[15] Ugwu, O. O., Kumaraswamy, M. M., Wong, A. & Ng, S. T. 2006. Sustainability appraisal in infrastructure projects (SUSAIP) Part 1. Development of indicators and computational methods. Automation in Construction 15: 239-251.

[16] Sohail, M., M.ASCE, Cavill, S. & Cotton, A. P. 2005. Sustainable Operation and Maintenance of Urban Infrastructure: Myth or Reality? Journal of Urban Planning and Development 131(1): 39-49.

[17] Little, R. G. 2005. Tending the infrastructure commons: ensuring the sustainability of our vital public systems. Structure and Infrastructure Engineering 1(4): 263-270.

[18] Yan, J. E., Kennedy, C., Saiz, S. & Pressnail, K. 2005. Toward sustainable neighbourhoods: the need to consider infrastructure interaction. Canadian Journal of Civil Engineering 32(1): 45-57.

[19] Alavi, M. & Leidner, D. E. 2001. Review: knowledge management and knowledge management systems: conceptual foundation and research issues. MIS Quarterly 25(1): 107-136.

[20] Kakabadse, N. K., Kakabadse, A. & Kouzmin, A. 2003. Reviewing the knowledge management literature: toward a taxonomy. Journal of Knowledge Management 7(4): 75-91.

[21] Dalkir, K. 2005. Knowledge Management in Theory and Practice. Oxford: Elsevier Inc.

[22] Kazi, A. S. 2005. Knowledge Management in the Construction Industry: A Social-Technical Perspective. London: Idea Group Publishing.

[23] Pathirage, C. P., Amaratunga, D. G. & Haigh, R. P. 2007. Tacit knowledge and organisational performance: construction industry perspective. Journal of Knowledge Management 11(1): 115-126.

[24] Maqsood, T. & Walker, D. H. T. 2007. Facilitating knowledge pull to deliver innovation through knowledge management. Engineering, Construction and Architectural Management 14(1): 94-109.

[25] Venters, W., Cornford, T. & Cushman, M. 2004. Knowledge about sustainability: SSM as a method for conceptualising the UK construction industry's knowledge environment. Journal of Computing and Information Technology CIT 13(2): 137-148.

[26] Chen, Z., Li, H. & Wong, C. T. C. 2003. An integrative analytical system for environmental management in construction projects. Automation in Construction 13(5): 621-628.

[27] Shelbourn, M. A., Bouchlaghem, D. M. & Anumba, C. J. 2006. Managing knowledge in the context of sustainable construction. ITcon 11: 57-71.